least consistent with the data for BeO. In both cases there should be different properties in the two directions of the hexagonal axis.

The fact that c/a is greater for Zn than for Be, but less for ZnO than BeO is hard to explain unless we assume a considerable rearrangement of electrons to take place during the formation of one of the oxides. It is interesting to note that another substance which possesses this structure is ice,[20] which tempts one to regard frozen water as an oxide of the formula $(OH_4)O$, the radical OH_4 being divalent, just as NH_4 is univalent and CH_4 is saturated.

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SOME CASES OF NERVE-DEAFNESS AND THEIR BEARING ON RESONANCE THEORIES OF AUDITION

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1. *Introduction.*—The present paper deals with certain cases of nerve-deafness and their bearing on the mechanical resonance theories of tone perception. The paper is thus a continuation of a recent one published in the February issue, 1922, of the *Physical Review* and like the earlier

one, is a result of further coöperation with some of the ear specialists of Chicago.

It is generally accepted among medical men that the purpose of an end-organ is to lower the threshold of perception of certain sensations. In the case of the ear, the complicated internal-ear structure is not only for the purpose of lowering the threshold of audition, but, according to all the mechanical resonance theories of pitch perception, it is also for the purpose of making possible the phenomenon of this perception. Data which have now been collected show with much certainty that these resonance theories are untenable and it is the purpose of the present paper to present some of these data. The results seem to show clearly that the sole purpose of the mechanical structure of the internal-ear is to lower the threshold of audition and that the power of pitch perception is a property of the nerves including their endings. According to this view, then, the power of pitch perception is in no way associated with the actual mechanical structure of the cochlea.

2. *Experimental Results.*—The details of the method of testing were described in the paper to which reference has already been made and these need not be discussed in this place. Many cases of nerve-deafness have been examined but only those that have a direct bearing upon the purpose in mind will be presented.

a. One of the most interesting set of curves for nerve-deafness is that shown in figure 1. This set is for a person 45 years of age. The upper curve was taken in December, 1920. The lower curve for the same ear was taken in March, 1922, so an interval of sixteen months had elapsed. The curves show that the ear functioned in a normal manner up to 1000 d. v. So, as pointed out in the previous paper, we know that no deficiency in hearing exists because of middle-ear trouble. During the period of sixteen months the impairment of hearing has become quite marked; requiring about 665,000 times as much current through the receiver for the threshold of audition at 3000 d. v. as is required by a normal ear. The minimum of the earlier curve has shifted from 3300 d. v. to 3000 d. v. during the interval. The range in frequency for which a deficiency in hearing exists includes lower pitches than were included in the first test, and, moreover, over the affected range the impairment is much more marked than indicated by the first curve. It is almost incredible that a person could be as deaf as indicated by these curves at some pitches and still have normal hearing at other frequencies.

In the case of the patient under discussion, near the threshold of audition at the higher pitches, say in the region of 3000 or 4000 d. v., the tones would break through, so to speak; they would be heard as pure tones with much intensity. A moment later it seemed as though the supply of nerve energy had been exhausted and the sensation of a pure tone would change

to a blurred noise of just audible intensity. When the tone was heard no noise sensation was present and when the noise was heard no tone was observed. So, it would seem that the same nerves were responding under both conditions and that a certain minimum amount of nerve energy was necessary for tone perception. It is quite improbable that such a variation as this could be due to the mechanical condition of the internal-ear but it would appear most reasonable to consider it due to a condition of the auditory nerve system whose impairment, without doubt, was responsible for the deficiency in hearing. Even though there was such an impairment in hearing due to the condition of the nerves and their endings the patient was able to recognize all the pitches when the tones were sufficiently intense.

b. In figure 2 is shown a group of six curves for the right and left ears of three partially deaf and dumb persons who had congenital deafness. Impaired hearing of this nature is caused, according to medical findings, by the incomplete or mal-development of the internal-ear system. These six curves are of much value from the theoretical viewpoint as will be seen later.

Curves 1 and 2 are for the two ears of a young man 25 years of age. Curves 3 and 4 are for those of a young girl 18 years of age and Curves 5 and 6 are for the two ears of a boy 10 years old. The first two curves are of the same general shape; both have their maximum depression at 3300 d. v., but the degree of hearing for the two ears is quite different. Curves 3 and 4 are also of the same general shape and the same is true of Curves 5 and 6. All three of these patients recognized all the pitches, the tones sounded of the same pitch when listened to by the two ears (that is there was present no indication of diplacusis for these cases) and the pitch discriminating power was apparently normal. Therefore, the auditory nerve systems for these three patients responded in a normal manner in regard to pitch perception. The sound intensity, of course, needed to stimulate the nerves in order to produce the sensation of sound, was far more than required for normal hearing; this being due, no doubt, to the structural condition of the cochlea.

Although these three persons were nominally deaf and dumb, all three of them recognized the difference between the fourteen fundamental vowel sounds when they were intoned in the patients ears. In the case of the girl the vowel sounds were repeated correctly by her. She was able to recognize and repeat, but with difficulty, spoken words and simple sentences. The results were not as satisfactory in the case of the boy. Nevertheless, he was able to repeat the vowel sounds with sufficient clearness to make it certain that he was able to distinguish the difference between these sounds.

c. In figure 3 are given two curves for patients each of whom were considered by the otologist totally deaf in one ear. The threshold curves

of audition showed that both patients were able to hear all the tones at sound intensities of not unusually large magnitudes, and furthermore both patients had about the same impairment of hearing. They were also able to recognize perfectly all the tones of the various pitches at the increased intensities. Care was taken to make sure that the patients were

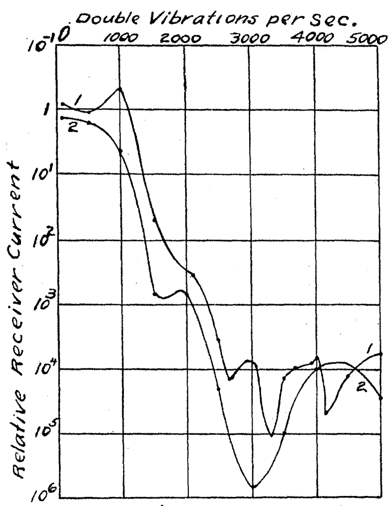

FIG. 1

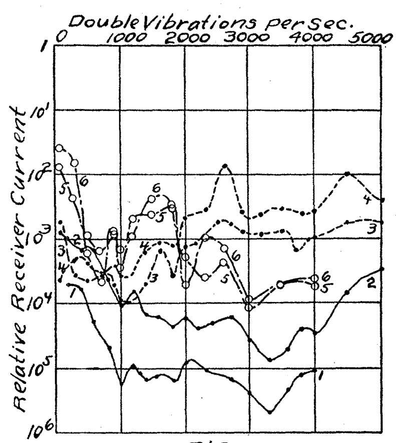

FIG. 2

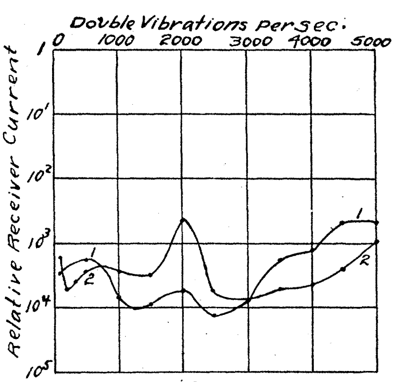

FIG. 3

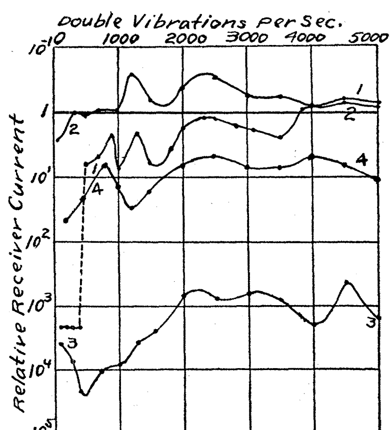

FIG. 4

hearing with the tested ears and not with the opposite ears. In the case of the patient represented by Curve 1 the opposite ear possessed normal hearing at 1000 d. v. and 4000 d. v. and it was assumed that the opposite ear was normal. The opposite ear, however, in the case of the patient represented by Curve 2 was quite defective in hearing. The possibility existed

that these patients were hearing in these opposite ears and that they were totally deaf in the other ears, as diagnosed. However, the moistened finger was placed in the ear which was not being tested and in the case of both patients the sensation of sound disappeared when the receiver was removed a cm. or so from the ear. They were able to hear when the receiver was brought close to but not in contact with the ear and they were unable to hear when the receiver was placed in contact with the bones of the head. There was also present the possibility that these two patients were not hearing the tones in the tested ears but through the eustachian tubes and the mouth to the opposite ears. Sufficient data are at hand, it is believed, to negate such a conclusion as this. It was apparent, then, that both patients heard by air conduction with the ears diagnosed as totally deaf. The diagnosis, of course, rested upon the fact that the structure of the cochlea was known to have been completely destroyed by disease and an operation in one of the cases. In spite of this destruction, however, both patients heard all the tones up to 5000 d. v. and their auditory nerve systems responded in a normal manner.

d. Two additional cases of true nerve deafness will be cited. The curves for these are shown in figure 4. Curves 1 and 2 are for a girl 20 years old whose ears were in perfect condition at the time of the test. She was affected on one side only by paralysis of the facial, auditory and vestibular nerves. These three nerves join one another at a definite and known location in the head. Since all three of the nerves were simultaneously affected and since they recovered at the same time, the exact location of the lesion was definitely known to the otologist. Curve 1 for this case shows an abrupt break between 400 and 500 d. v. At pitches below the break all the tones were heard as some sort of a noise corresponding to the noise referred to in the discussion of the curves in figure 1. The noise rather than a tone was present even when two or three thousand times as much current was passing through the receiver as was required for audition by a normal ear. Above the break in the curve the tones were perceived as pure ones at intensities only slightly greater than were required by normal ears. Thus, the nerves, stimulated in a perfectly normal manner, would not transmit the sensation of a pure tone at any of the pitches below the break but would transmit the sensations undistorted at all pitches above this point. A lesion, then, in the nerve proper may prevent the formation and transmission to the brain of a stimulus corresponding to a pure tone.

This patient was first tested on February 4, 1921, and was again tested on March 7, 1921. During this period she had recovered completely and her hearing as shown by Curve 2 in figure 4 was equivalent to or better than normal. So, with the disappearance of the cause of the paralysis there was an immediate return to normal hearing and pitch perception.

The concluding case to be cited was also one of pure nerve lesion due to pressure on the auditory nerve brought about by the growth of a cerebral tumor. Curve 3, figure 4, shows the relative degree of hearing possessed by the patient's left ear. The right ear was not greatly affected; as shown by Curve 4 it required for minimum audition a relative receiver current of 48.5 at 200 d. v. and improved with increasing pitch, requiring a relative receiver current of 11.5 at 5000 d. v. The curve (4) for the right ear, however, is almost exactly of the same shape as that (3) for the left ear. The lesion, then, had affected both ears alike qualitatively. In the case of this patient it has not been found possible to secure additional curves.

These two cases of true nerve deafness show the maximum depression in hearing at the lower frequencies, whereas for most cases of what is termed nerve deafness caused by lesions within the internal-ear the greatest depressions occur at the higher pitches.

Many additional curves have been taken on patients with nerve deafness, but for the purpose of the present paper it is believed that the cases cited are sufficient to establish the object in view.

3. *Theoretical Bearing of the Cases Cited on the Mechanical Theories of Tone Perception.*—As stated in the introduction, it is believed that the data presented herewith show conclusively that the sole purpose of the mechanical structure of the internal-ear is simply to lower the threshold of audition and that mechanical resonance of this structure is not in the slightest degree responsible for the phenomenon of tone perception. The group of curves shown in figure 3, for patients known to have internal-ears completely modified, showed normal pitch perception but greatly reduced sensitivity. If mechanical resonance of this structure were responsible for tone perception, then this perception would have been completely destroyed in these two cases. This sense remained unmodified, but the greatly decreased sensitivity of hearing would suggest conclusively that the internal-ear structure is for the prime purpose of lowering the threshold of audibility.

This view is much strengthened by the group of six curves in figure 2 for deaf-mutes all of whom showed simply reduced sensitivity of hearing without any apparent modification of the sense of tone perception. Among medical men it is considered that congenital deafness of this sort means that the cochlea is only partially developed. Accepting this view as even partially correct, we are forced to the conclusion that all theories of audition which are based on mechanical resonance of the internal-ear are untenable.

The data for Curve 1 are the same as given in figure 17 of the paper published in the February 1922 issue of the *Physical Review*, p. 88. The argument against the mechanical resonance theories as stated in this earlier paper, pp. 95–96, can be repeated here with even more decisiveness than

was given there because the patient has become more deaf at the higher pitches as shown by Curve 2, figure 1, since the first curve was taken.

It would seem, therefore, even in the case of the complete modification of the internal-ear mechanism that a person can hear in a normal manner, provided the tones are sufficiently intense and provided there has not been a complete destruction of the nerve endings or of the nerves themselves in which case we should expect complete deafness. Only one such case has as yet been found and in this case the patient was unable to hear at any pitch in either ear with as much as 5×10^6 times as much current passing through the receiver as was required by a normal ear.

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THE QUANTITATIVE INFLUENCES OF CERTAIN FACTORS INVOLVED IN THE PRODUCTION OF CYANOSIS

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Lundsgaard has shown that the appearance of cyanosis depends on the mean concentration of reduced hemoglobin (C) in the capillary blood. This concentration he estimated as

$$C = \frac{A + V}{2} \qquad (1)$$

where A is the arterial, V the venous concentration of reduced hemoglobin. The effect of certain physiological factors contributing to C is estimated as follows. We let T represent the total hemoglobin concentration in the blood, l the fraction of total hemoglobin passing in reduced form through the aerated parts of the lungs, D the concentration of reduced hemoglobin formed by deoxygenation of the blood as it passes from arteries to veins through the tissue capillaries. In certain pathological conditions a fraction of the venous blood reaches the arteries without traversing aerated parts of the lungs and therefore carries reduced venous hemoglobin directly into the arterial blood. This fraction we designate as α. A, T, and C have the significance indicated above.

When $\alpha = O$, only aerated blood entering the arteries, $A = l\,T$. When however, α has a positive value, the reduced hemoglobin of the arterial blood represents the sum of that in the fraction α, of venous blood entering